

Electrochemical Energy Storage and Power Sources for NASA Exploration Missions”

Richard Baldwin

**10th Electrochemical Power Sources R&D Symposium
Williamsburg, VA
August 20 - 23, 2007**

An overview of NASA's electrochemical energy storage programs for NASA Exploration missions is being presented at the 10th Electrochemical Power Sources R&D Symposium, which is being held in Williamsburg, VA on August 20-23, 2007. This public domain venue, which is sponsored by the U.S. Navy and held every two years, serves as a forum for the dissemination of research and development results related to electrochemical energy storage technology programs that are currently being supported and managed within governmental agencies. Technology areas of primary interest include batteries, fuel cells, and both overview and focused presentations on such are given by both governmental and contractual researchers. The forum also provides an opportunity to assess technology areas of mutual interest with respect to establishing collaborative and/or complementary programmatic interactions.



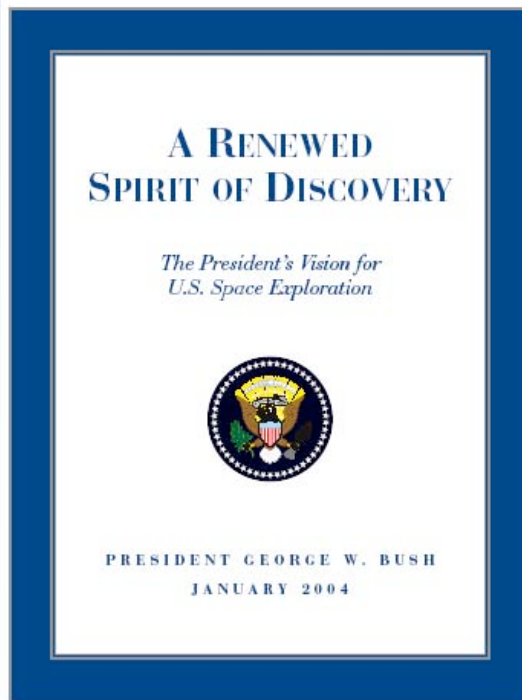
Electrochemical Energy Storage and Power Sources for NASA Exploration Missions

10th Electrochemical Power Sources R&D Symposium
Williamsburg, VA
August 20 - 23, 2007

Dr. Richard S. Baldwin
Electrochemistry Branch
NASA Glenn Research Center
Cleveland, Ohio
(216) 433-6156
Richard.S.Baldwin@nasa.gov

National Vision for Space Exploration

THE FUNDAMENTAL GOAL OF THIS VISION IS TO ADVANCE U.S. SCIENTIFIC, SECURITY, AND ECONOMIC INTEREST THROUGH A ROBUST SPACE EXPLORATION PROGRAM



Implement a sustained and affordable human and robotic program to explore the solar system and beyond

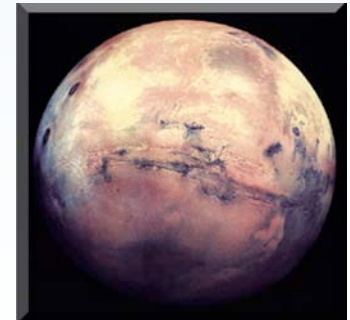
Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;

Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and

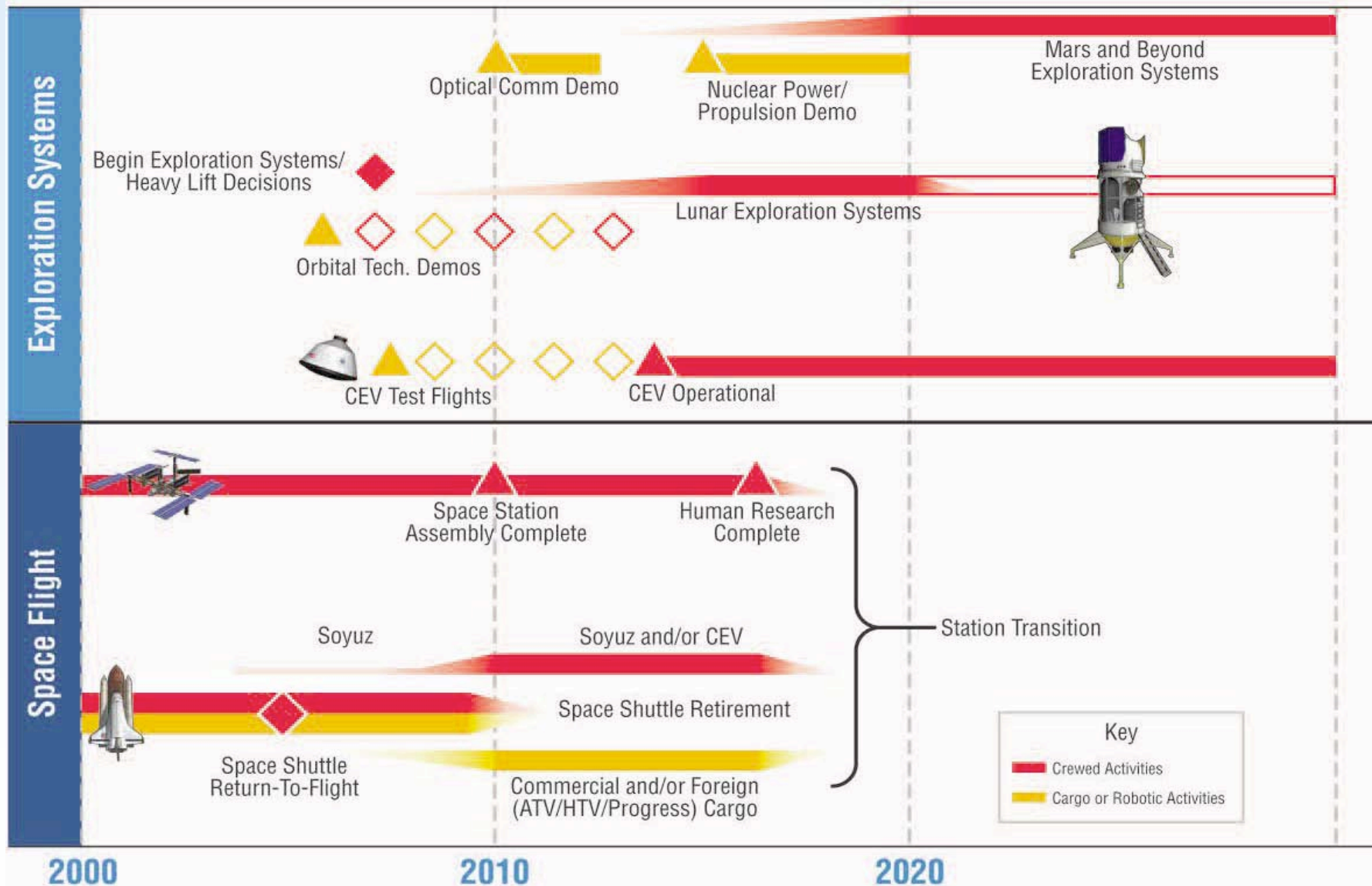
Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

Preparing for Mars Exploration: First Stop, Our Moon

- Use the Moon as a test bed to reduce risk for future human Mars missions
- Advance technology to reduce mission costs and support exploration
- Perform systems testing for reliability in harsh environments
- Expand mission and science surface operations experience
- Build human-machine collaboration to achieve more than either alone
- Break the bonds of dependence on Earth with closed-loop life support
- Develop and test power generation and propulsion
- Invest in common hardware for Moon, Mars, and other Exploration objectives



Exploration building blocks will provide the capabilities necessary for exploration of the solar system and beyond



NASA's Exploration Architecture

Exploration Systems Mission Directorate

Dedicated to supporting the Vision for Space Exploration by developing new capabilities, supporting technologies and foundational research that enables sustained and affordable human and robotic exploration

- **Constellation Program** - Responsible for Orion crew exploration vehicle (CEV) and Ares launch vehicles development projects
- **Advanced Capabilities Division** – Provides knowledge, technology and innovation. Matures, integrates and transitions advanced technologies to Constellation and Robotic missions
 - **Human Research Program (HRP)**
 - **Lunar Precursor Robotic Program (LPRP)**
 - **Exploration Technology Development Program (ETDP)** – Multiple focused projects to develop enabling technologies to address high priority needs for lunar exploration. Matures technologies to the level of demonstration in a relevant environment
 - **Energy Storage Project**



NASA Mission Applications

Near-term:

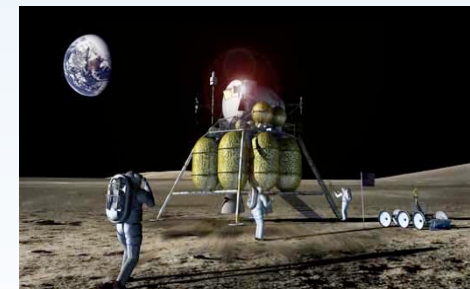
- Orion (Crew Exploration Vehicle, CEV)
- Ares I (Crew Launch Vehicle, CLV)

Far-term:

- Ares V (Cargo Launch Vehicle, CaLV)
- Lunar Precursor and Robotics Program (LPRP)
- Lunar Surface Access Module (LSAM)
- Rovers, Habitats and EVA



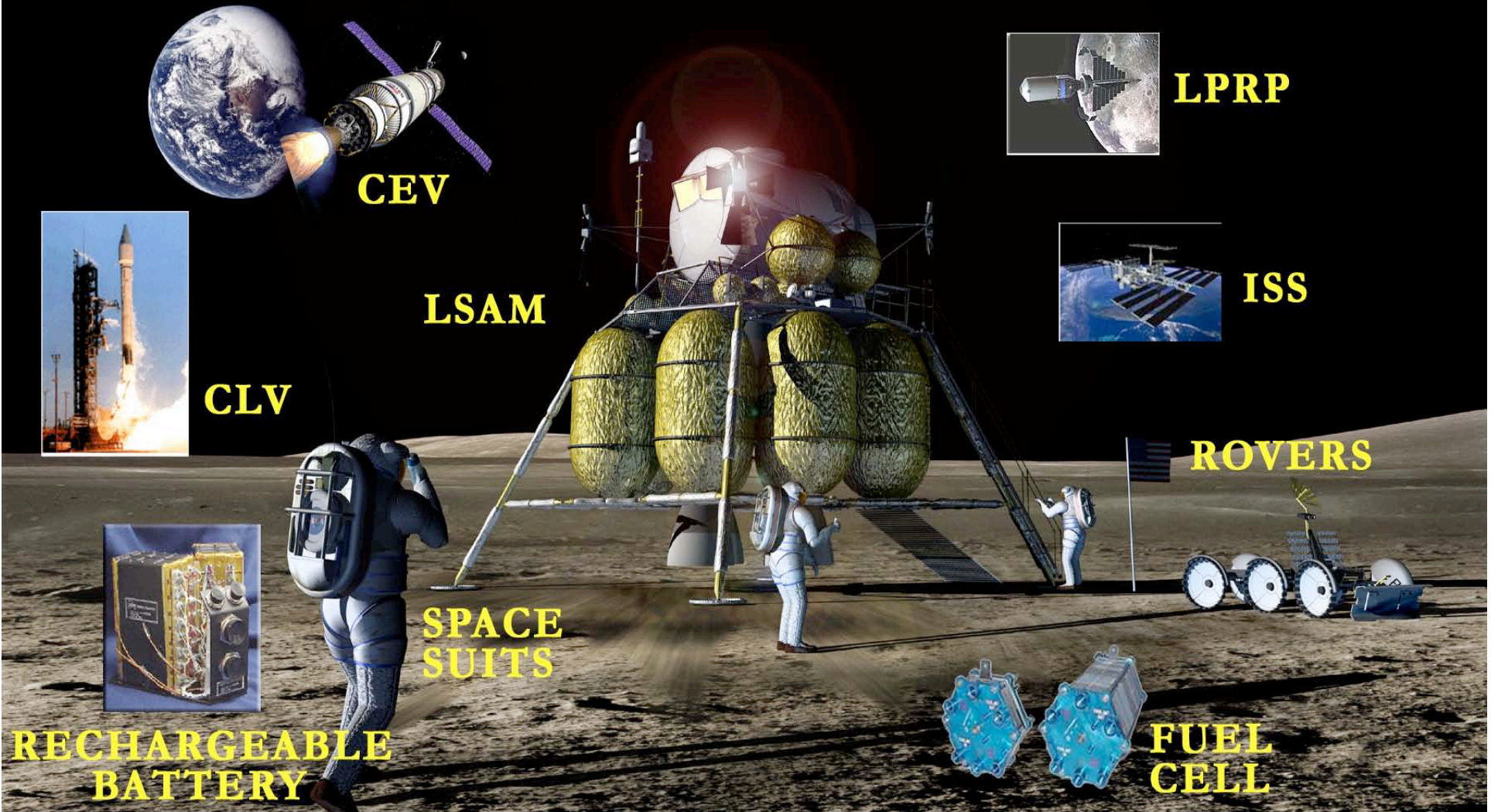
ETDP Energy Storage Project



Addresses Development of Advanced Batteries and Fuel Cells

Maturation of near-term technologies and development of long-lead technologies for lunar exploration missions. Technology development to achieve TRL 6 - phased to meet technology mission insertion dates

Energy Storage Technology for Exploration Missions



NASA Glenn Research Center

**Jet Propulsion Laboratory
Marshall Space Flight Center**

**Johnson Space Center
Goddard Space Flight Center
Kennedy Space Center**

Energy Storage Project Overview

NASA / Industry / Academia Partnerships

- NASA Centers - GRC – Lead, JPL, JSC, MSFC, KSC, GSFC
- Industry – T/J Technologies, Inc., Lockheed Martin, Quallion
- Grants - University of Texas at Austin, USC, University of Akron, Texas A&M, CalTech, Virginia Commonwealth

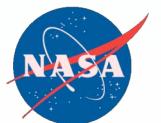
NASA SBIR Program Participants – Infinity Fuel Cell & Hydrogen, Inc., ElectroChem, Inc., Distributed Energy Systems, Giner, Inc., Yardney Technical Products, Inc., T/J Technologies, Inc., Santa Fe Science & Technology, Inc.

NASA Innovative Partnership Program (IPP) – T/J Technologies, Inc., ABSL Space Products, Northrop Grumman Space Technology

Exploration Mission Energy Storage Requirements and Trade Studies

Space-Rated Lithium-ion Batteries Technology Development

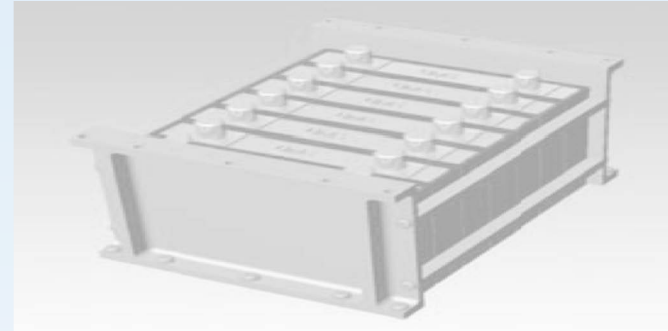
Fuel Cells for Surface Power Technology Development



Space-Rated Lithium-ion Batteries Objectives

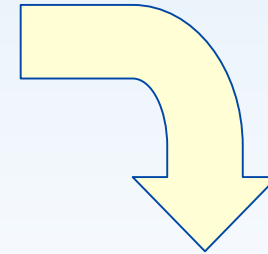
Develop a **common battery module** that addresses technology gaps to meet Exploration challenges

- Human-rated Safety and Reliability
- Wide Operating Temperature Range
- Light-weight / Low-volume



Approach via focus technology development efforts

- Trade Studies and Requirements Assessments
- Cell Component Development
- Test and Demonstration
- Module Development
- Multi-mission Support

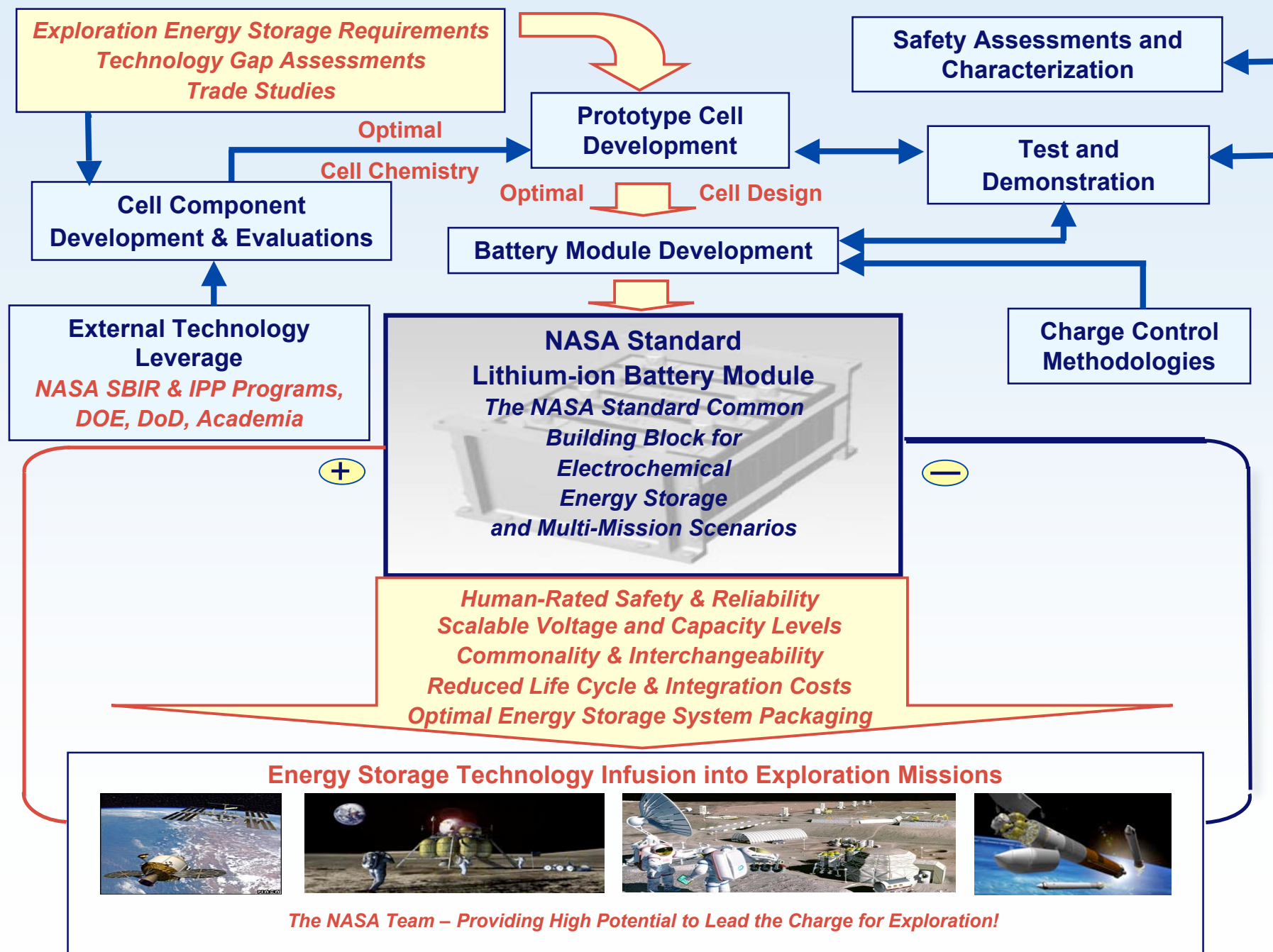


to afford mission-enhancing attributes

- Modularity / Scalability
- Commonality / Flexibility
- Optimal system packaging
- Life cycle & integration cost efficiency

Deliver a prototype module at
TRL 6 by FY11 for infusion into
LSAM PDR

ETDP Energy Storage Project – Space-Rated Lithium-ion Batteries Task



Fuel Cells for Surface Power Objectives

Develop fuel cells / regenerative fuel cells (RFCs) for Exploration surface power, which encompasses technologies to address unique environmental requirements

- Potable water production
- Provide long mission durations
- RFC's enable near-term implementation of storage for base power (combined with PV)

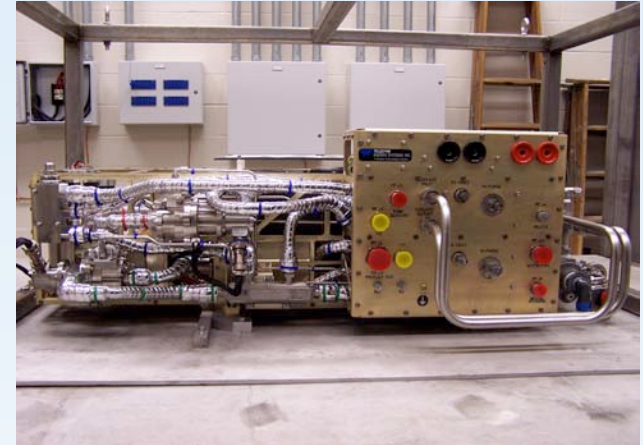
Approach via focused technology development efforts

- Leverage commercial sector advances
- Flow-through and non-flow-through system technologies
- High-pressure electrolysis
- Balance-of-plant / passive ancillary components



to address three fuel cell classes

- <1 kW for EVA portable life support system
- 8 kW for un-pressurized rovers
- 25 kW for RFC surface power and pressurized rovers



Demonstrate TRL 6 for RFC systems by 2014

Additional Aerospace Program Areas Being Supported to Enhance Overall Mission Energy Storage Technology Needs

Near-term Constellation Program (Orion and Ares upper stage) and LSAM

- **Systems engineering and integration support**
- **Trade studies – cell/battery chemistry / sizing, power technology options**
- **Cell/battery general, safety and mission-specific performance testing**

NASA Aeronautics Research Mission Directorate (ARMD) projects

Earth-orbiting spacecraft / ISS / satellites

Deep-space / planetary probes / surface rover exploration vehicles

EVA / spacesuit power systems

Dual-use / governmental and commercial technology needs

NASA Aerospace Flight Battery Systems Working Group / NASA Engineering and Safety Center (NESC)

- **Addresses critical battery-related performance / manufacturing issues for NASA and the aerospace community → Lithium-ion battery focus**



NASA Glenn Electrochemistry Branch

Battery Development Facilities and Capabilities

Facilities

- Laboratories with SOA analytical and electrochemical characterization capabilities
- Dry room (600 ft²) with 1% relative humidity for handling moisture sensitive materials used in lithium-based batteries
- State-of-the-art battery cycling facilities with >200 independent test channels (1-200 Ahr / 1-50 V)
- Environmental chambers to evaluate performance as a function of temperature (-75 °C to +200 °C)
- Accelerating Rate Calorimeter (ARC)



Capabilities

- Fundamental electrochemical research - component development and characterization with state-of-the-art analytical test capability
- Cell/Battery Design
- Cell/Battery Performance and Life Testing
- Cell/Battery Safety Testing
- Battery Performance Modeling
- Environmental Testing

NASA Glenn Fuel Cell Development & Evaluation Facilities



Hydrogen/Air Fuel Cell Test Facility
Stack and subsystem testing up to 12 kW
(Can be modified for other fuels)



Regenerative Fuel Cell Test Facility
Performance evaluation of fuel cell, electrolyzer
and ancillary components within a closed-
loop regenerative fuel cell system



Fuel Cell Development Laboratory
Fundamental electrochemical characterization
and component development
Capable of testing stack and subsystems up to
5kW



Fuel Cell Testing Laboratory
3 test cells capable of testing complete fuel cell,
electrolyzer and regenerative systems
up to 25kW

NASA Glenn Electrochemistry Branch

Complimentary Facilities and Capabilities



Imaging and Material Analysis Laboratory

Surface and Thermal Analysis Capability

- Inductively Coupled Plasma Optical Emission Spectrometer
- Scanning Probe Microscope
- Scanning Electron Microscope Energy Dispersive Spectrometer
- Stereomicroscope
- BET Surface Area Analyzer



Thermal and Material Analysis Laboratory

Molecular analysis, particle size distribution, thermal property analysis

- Differential Scanning Calorimeter
- Fourier Transform IR Spectrometer
- Thermogravimetric Analyzer (TGA)
- Raman Spectrometer
- Particle Size Analyzer

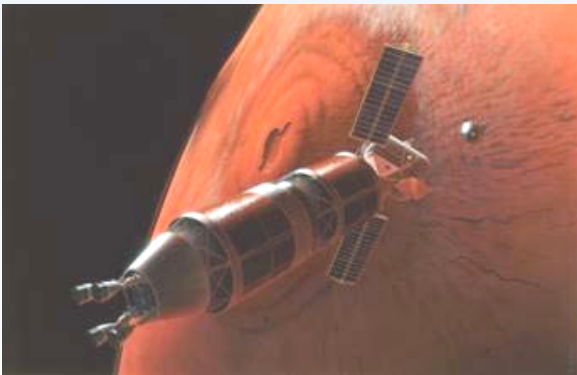


In Summary...NASA Glenn is Focused on Exploration

Unique Combination of Competencies and Capabilities

- Space flight systems development
- Technology development

Requirements and Systems



Constellation



Exploration Systems R&T



Human Systems R&T

...and collaboration is the key to success

Informational Resources

For current detailed information and for future updates concerning plans and strategies relevant to NASA's missions and partnering opportunities:

www.nasa.gov/centers/hq

www.exploration.nasa.gov

For additional information about NASA Glenn's Space Flight Systems, Advanced Capabilities and Exploration projects:

<http://spaceflightsystems.grc.nasa.gov>

For information about specific programs and collaborations with the NASA Glenn Electrochemistry Branch, contact Ms. Michelle Manzo at:

Michelle.A.Manzo@nasa.gov or via phone at 216.433.5261